DOI:
10.1075/lab.14020.tyt

Document Version
Peer reviewed version

Citation for published version (APA):
Tytus, A., & Rundblad, G. (2016). Cross-language priming as a means of investigating bilingual conceptual representations: a comparison of visual and auditory modality. *Linguistic Approaches to Bilingualism*, *6*(4), 440-466. https://doi.org/10.1075/lab.14020.tyt

Cross-language priming as a means of investigating bilingual conceptual representations: a comparison of visual and auditory modality

Agnieszka Ewa Tytus[1], Gabriella Rundblad[1]

[1] King's College London, DEPS, Franklin-Wilkins Building, WBW, Waterloo Road, London, SE1 9NH, UK, agnieszka.tytus@kcl.ac.uk & gabriella.rundblad@kcl.ac.uk

ABSTRACT

Cross language priming in the visual modality is a well established paradigm that offers insights into the representation of the bilingual mental lexicon; however, here we employ a novel form of priming, (i.e., an animacy decision task), to test previous outcomes. In addition, this study is the first to carry out an auditory priming task with bilingual Chinese-English speakers. Thus, we report on two experiments in which the participants decided whether visually (Experiment 1) or auditorily (Experiment 2) presented stimuli were exemplars of living entities or non-living things. The tasks allowed for addressing the priming effect, the priming asymmetry effect, and in turn allowed for testing the Revised Hierarchical Model (Kroll & Stewart, 1994). Priming effects, where the related targets were responded to more rapidly compared to unrelated targets, were observed in both modalities in the L1 to L2 condition; however, no priming effects were found from L2 to L1. The findings obtained in this study support the use of primed animacy decision tasks in either modality as a valid tool for investigating bilingual lexical memory. Also, the observed priming effects allow for retaining the RHM in its original form.

Keywords: bilingualism, mental lexicon, priming, animacy decision task, visual modality, auditory modality

1. Introduction

The organization of the bilingual mental lexicon has proved to be one of the most controversial topics in the field of bilingualism (Pavlenko, 2009). Many researchers agree that the two languages of a bilingual are represented separately at the lexical level (i.e., orthography, phonology). French & Jacquet (2004, p. 88) explained that "support for separate lexical stores came largely from the lack of any convincing evidence of cross language repetition priming". However, there is still considerable debate over the extent of integration at the conceptual level (Francis, 2005; Pavlenko, 2009). Substantial empirical evidence has been found supporting both a fully integrated conceptual representation on the one hand (Kroll & Stewart, 1994; Potter et al., 1984), and a distributed representation on the other (De Groot, 1995; Dong et al., 2005; Finkbeiner et al., 2004; Pavlenko, 2009). Moreover, the 'architecture' of the bilingual lexical memory has been depicted in detail by many different frameworks, for example, the Revised Hierarchical Model (Kroll & Stewart, 1994), the Shared Asymmetrical Model (Dong et al., 2005), the Modified Hierarchical Model (Pavlenko, 2009), and also several computational models, for instance, BIA+ (van Heuven & Dijkstra, 2010) or DevLex II (Zhao & Li, 2010), to mention a few. In general, proponents of these models agree that there are two levels of representation, (i.e., lexical and conceptual), that are hierarchically organized; however, regarding other aspects, their structures differ, especially when it comes to the theoretical propositions regarding the conceptual level. Under the Revised Hierarchical Model (Kroll & Stewart, 1994), it is claimed that the conceptual store is fully overlapping across the two languages, whereas the other models claim certain levels of distribution at the conceptual level across the two languages. It has been suggested, however, that the mixed findings reported in the literature are not necessarily due to different cognitive processes being measured, but rather, due to differences in methodology, statistical analyses, and proficiency across the samples of bilingual participants (Grosjean, 1998). For instance, the comparison of published masked cross-language priming studies made by Schoonbaert et al. (2009) clearly exemplified the variety of task designs (differing prime presentation, use of blank, different length of SOA), variety in the number and type of stimuli used and types of scripts investigated, which could potentially lead to different results. Therefore, in order to address the shortcomings stemming from the use of different methodologies and at the same time to investigate the notion of bilingual sharedness at the conceptual level of representation, a well established and often used paradigm, namely, a priming task in a visual modality is compared with an auditory version of the task in this study. Most previously reported research that relied on an auditory priming task was conducted with monolingual speakers. Thus, the novel aspect of employing cross-language auditory priming with bilingual speakers is pursued in this investigation. Moreover, the focus of this research is on the representation of conceptual information in the bilingual lexical memory and the possible sharedness or distribution of it. The processing aspect (selective vs. non-selective access) is not being directly examined here. All in all, our aim is to verify if similar outcomes, a priming effect and a priming asymmetry effect, can be observed regardless of the mode of presentation, either visual or auditory. This, in turn, should provide more concrete evidence for conceptual interdependence in bilinguals and indirectly offer support for the RHM (Kroll & Stewart, 1994).

2. The Revised Hierarchical Model

The Revised Hierarchical Model (RHM) (Figure 1) is probably the only remaining psycholinguistic model that presents the conceptual level of information as fully overlapping. It proposes separate lexical representations for each language, one for the first language (L1) and one for the second (L2) but one common conceptual representation for both languages. It also assumes that the link between L1 and the shared concepts is stronger than that between L2 and those concepts. The differing strength of connections reflects the fact that bilinguals (especially successive bilinguals) often acquire words in L1 first and they rely a lot on translation from L2 to L1 in order to access meaning of L2 words, especially during early stages of language learning. A number of studies (e.g., Kroll et al., 2002; Sunderman & Kroll, 2006; Talamas et al., 1999) have confirmed the propositions outlined by the RHM. It has also been suggested that bilinguals who are less proficient in L2 use the word association route more often than bilinguals of higher language proficiency, who rely more on the concept mediation route (Talamas et al., 1999). This developmental aspect captured by the RHM has been seen by many researchers (e.g., Pavlenko, 1999) as the most significant contribution of this framework to the understanding of the bilingual lexical memory.

However, in recent years, the RHM has been subject to a substantial critique. For instance, Brysbaert and Duyck (2010) said that the fundamental principles of the model are questionable due to the fact that there is little evidence for separate lexicons and language selective access. In addition, the strength of the connections between L2 words and meanings seems to be greater than proposed by the model. Consequently, Brysbaert and Duyck (2010) made the suggestion that it is probably time to abandon the RHM and focus on computational models, for example, the Bilingual Interactive Activation Model (BIA) (Dijkstra et al., 1998) or the BIA+ Model (Dijkstra & Van Heuven, 2002). However, Kroll et al. (2010) refuted the critique by stating that the original RHM never assumed lexical non-selectivity as little evidence was available supporting this notion at the time when the model was proposed. Furthermore, Kroll and colleagues (2010) put forth the point that parallel (non-selective) access does not necessarily suggest an integrated lexicon (van Heuven et al., 1998). Additionally, these authors admitted that the assumption of the RHM about understanding L2 words via L1 translation equivalents was not correct (Kroll et al., 2010). Nonetheless, evidence as early as 1995 demonstrated that less proficient bilinguals can also employ the concept mediation route, (e.g., in a categorization task) (Dufour & Kroll, 1995).

Consequently, Kroll et al. (2010) refuted the critique directed towards the model and concluded that even though the RHM is more than fifteen years old, it is still potent enough to account for new findings presented in the field.

The theoretical propositions regarding the conceptual level of representation and the differing strength of the connections between L1 and concepts and L2 and concepts outlined by the model are investigated in this study with a group of bilingual Chinese-English speakers. So far, the great majority of the bilingual memory representation studies have focused on a comparison of Indo-European languages, taking into account the common origin of the languages and similarities that can be found in the given systems. A number of studies compared Dutch-English participants (e.g., De Groot & Poot, 1997; Kroll & Stewart, 1994; van Hell & De Groot, 1998), Spanish-English participants (e.g., Altarriba, 1992), Catalan-Spanish participants (e.g., Duñabeitia et al., 2010; Guasch et al., 2011), Dutch-French participants (e.g., Duyck & Warlop, 2009a) and French-English participants (e.g., Smith, 1991; Williams, 1994), but few researchers have paid attention to a comparison of such distinct linguistic systems as Chinese and English. Comparative studies carried out by Dong et al. (2005), Jiang (1999), Jiang & Forster (2001), Li et al. (2009), Wang & Forster (2010), and Wang (2013) can be found among those few that investigated the lexical memory representation of Chinese-English bilinguals. These two languages have a number of unique characteristics (e.g., Latin alphabet vs. characters, or sentence final accent vs. tones) that may account for differences in the way information in both systems is represented and processed. Therefore, the novelty of investigating this pair of languages may reveal insights about the representation of the bilingual mental lexicon that have not been uncovered before.

(Insert Figure 1 about here)

3. Priming effect and priming asymmetry

As pointed out by Grainger (2008), the masked priming paradigm has recently become a key research tool that allows for investigation of all aspects of visual word recognition. Priming enables exploration of how words are stored and connected in memory, and it allows for the measurement automatic cognitive processes (Altarriba & Basnight-Brown, 2009). Furthermore, in masked priming, the primes are presented at such a quick interval that participants tend not to be aware of them; they can only consciously recall target words. Consequently, masked priming allows for the elimination of translation strategies, whilst at the same time encouraging on-line processing (Kim & Davis, 2003).

In cross-language priming tasks, in which for instance, a prime is presented in Chinese (L1) and a target in English (L2), the cross-language priming effect has been reported to be asymmetrical. This means that it tends to be stronger from L1 to L2 and weaker as well as inconsistent the other way round (e.g., Finkbeiner et al., 2004; Gollan et al., 1997; Jiang, 1999; Jiang & Forster, 2001; Jin, 1990; Voga & Grainger, 2007). Various representational and processing accounts have been put forth to give reasons for the asymmetry effect. The representational hypothesis, which is based on the theoretical predictions of the RHM, explains the findings in terms of different strengths of connections between the two languages. That is, semantic priming effects from L1 to L2 should be stronger than vice versa, since the connections between L1 and concepts are stronger than those between L2 and concepts, as exemplified by the RHM (Kroll & Stewart, 1994). In other words, the representational account implies that if an L1 word is presented as the prime, then it activates more conceptual information, and consequently, a greater amount of conceptual activation is spread to the target L2 word, whereas the same pattern is not true for the reverse direction (Basnight-Brown & Altarriba, 2007:956). This particular explanation is tested in this study.

In addition to the representational hypothesis, there are several other processing accounts that have been put forth. For instance, Grainger and Beauvillain (1988) suggested that the time that is given for L2 prime processing may not be enough for the participants to be able to recognize it, especially if the level of L2 proficiency is low. On the other hand, Gollan et al. (1997) proposed that the L2 prime might be processed more slowly than the L1 target, whereas according to the general activation level hypothesis, L2 is assumed to be less dominant, and therefore an L2 prime would be less active and less available for processing than an L1 prime. Jiang (1999) tested these three processing hypotheses, varying the presentation conditions of primes and targets by introducing a 50ms blank interval (Experiment 3); a 150ms backward mask (Experiment 4); and by presenting targets in two languages in a single block (Experiment 5). The researcher found a strong translation priming effect in the L1 to L2 language condition, but the priming effect in the opposite was smaller or not visible at all. Therefore, Jiang (1999) concluded that the three processing accounts are not satisfactory and the asymmetry can be better explained in terms of a representation-oriented approach. Following Jiang's findings, the priming asymmetry and more specifically, the representational account as outlined by the RHM (Kroll & Stewart, 1994), is addressed in this study with the use of visual as well as auditory masked priming tasks. Before the design of both paradigms is presented, an overview of priming in an auditory modality from studies with monolingual participants will illustrate the scarcity of available findings and the need to replicate it with bilingual speakers.

4. Priming in an auditory modality

Previous priming studies that focussed on groups of Chinese-English bilinguals have so far been limited to visual word recognition (e.g., Chen & Ng, 1989; Dong et al., 2005; Jiang, 1999; Jiang & Forster, 2001; Li et al., 2009; Wang & Forster, 2010). Since Chinese is a logographic system, whereas English is an example of an alphabetic language, this conspicuous difference in scripts could push participants into a bilingual mode (Grosjean, 1998) and skew the results. That is, participants are supposed to view a masked priming task as monolingual in nature when responding to target items in a given language in a blocked-language design. However, if they become aware of the primes in the language not attended to this may influence their latencies. The participants might start relying on more conscious strategies while processing the stimuli, (e.g., translation, the expectancy and semantic-matching strategies) (Neely, 1991; Neely et al., 1989) and in consequence, this may influence the automatic language processing. According to Kim and Davis (2003), these strategies have to be eliminated in order to encourage on-line processing of the stimuli.

In this study, a comparison between a visual priming paradigm and an auditory one is performed in order to address the notion of sharedness at the conceptual level of representation in a bilingual mental lexicon. Holcomb and Neville (1990) compared visual and auditory priming using event related potentials (ERPs) and behavioural measures (RTs). They reasoned that the behavioural and electrophysiological findings should be alike for the two modalities if the mechanisms are similar. The results, collected from 16 native English speakers from a primed lexical decision task, revealed a robust semantic priming effect in both modalities. Also, the recorded N400 amplitude was smaller when related target items rather than when unrelated words were presented in both the visual and auditory modalities. However, the ERPs and RTs priming effects in the auditory condition were significantly larger than those for the visual task, they were distributed differently on the scalp, and they differed in the time course of the N400 effect. Based on the above, Holcomb and Neville (1990) concluded that even though there might be an overlap between the priming processes seen in visual and auditory modalities, the processes are not identical. Also, Anderson and Holcomb (1995) examined auditory and visual semantic priming across three stimulus onset asynchronies (SOAs), 0ms, 200ms, and 800ms and demonstrated that the semantic priming effect in the auditory experiment was again greater than in the visual experiment. Furthermore, it was shown that, in the auditory experiment, the priming effect correlated positively with SOA; it was greater with longer SOAs (0SOA - 18ms; 200SOA – 57; 800SOA – 142ms), whereas in the visual experiment the priming decreased with extended SOA (0SOA – 53ms; 200SOA – 32ms; 800SOA – 19ms). Anderson and Holcomb (1995) concluded that the information from the targets may become available at different rates in the two modalities.

Drawing on the above reported findings and on the assumption that both auditory and visual words share the same concepts, they convey the same meaning and as they "retain the same identity in terms of [their] syntactic, phonological, and orthographic word forms" (Francis et al., 2010, p. 788), for our study both visual and auditory stimuli were employed. Although previous studies have demonstrated asymmetries between the two modalities, we predicted similar processing patterns, but longer RTs for the auditory modality. This comparison was employed in order to evaluate a wider cohort of previous results and for possible generalizability of the findings. The specific designs as well as outcomes from the visual and auditory priming tasks are presented separately in the forthcoming sections.

5. Experiment one – visual priming

The purpose of the first experiment was twofold. First, it was aimed at verifying whether or not the priming effect was observable in an animacy decision task that is *conceptually-driven,* that is, one that does not rely on the processing of a form level of presented stimuli but on a conceptual one (Durgunolu & Roediger, 1987). Second, it had the purpose of investigating the notion of the priming asymmetry effect, (i.e., greater magnitude of priming in the L1 to L2 language direction as compared to the reverse condition). Based on the review of previous literature, we predicted a two-way interaction between prime relatedness and language direction, with a priming effect visible from L1 to L2 but not necessarily from L2 to L1. Language proficiency was controlled for as a possible covariate in the priming asymmetry effect.

5.1 Participants

All the participants were recruited from the University of Hong Kong and the Chinese University of Hong Kong, with each completing a primed animacy decision task as well as a language background questionnaire. The information collected from the questionnaires was used to select only those participants who were between the ages of 18 and 25, dominant in Mandarin Chinese, and right-handed. From an initial pool of 126 Chinese English bilinguals that took part in both the visual and auditory tasks, data from 96 participants were retained for the final analysis. From this large pool of participants, 50 took part in the visual Experiment: 27 respondents attended to the items in the L2 to L1 language direction and 23 in the L1 to L2 one (between-group design). The two groups of participants in the visual task did not differ with regard to age[1] [χ^2 (1) = 3.632, $p > 0.05$]. Also, no difference was reported in respect of gender [χ^2 (1) = .972, $p > 0.05$] and education [χ^2 (1) = 1.155, $p > 0.05$]. Furthermore, no difference for two continuous variables, namely, (1) age at which participants started learning English, $M_{ageL2\text{-}L1}$ = 8.81 (2.71) vs. $M_{ageL1\text{-}L2}$ = 8.65 (2.46), [t (48) = -1.917, $p > 0.05$] and (2) length of residency in Hong Kong, $M_{stayL2\text{-}L1}$ = 1.11 (0.32) vs. $M_{ageL1\text{-}L2}$ = 1.61 (1.31), [t (48) = 0.220, $p > 0.05$] was reported. Furthermore, English language proficiency, which was evaluated on the basis of a self-rating scale, is illustrated in Table 1. No statistically significant differences were found between the two groups in the visual condition and groups in the auditory one [t_{visual} (48) = 0.226, p > 0.05; $t_{auditory}$ (44) = 0.263, p > 0.05]. A self-rating scale was used following Lim et al.'s (2008:393) claim that an increasing number of research investigations have found that self-assessment of language proficiency correlates with scores obtained on a standardised proficiency test, which thus indicates that it is a valid and reliable measure of assessing language skills.

(Insert Table 1 about here)

5.2 Materials

The materials comprised 80 pairs of words that were translation equivalents in Chinese and English selected at random from an initial list of 240 items. The stimuli included 30 translation equivalents, 30 unrelated pairs (words in L1 and L2 that did not share meaning) and 20 fillers. Some of the stimuli were chosen from lists used in the studies carried out by Azuma and van Orden (1997), Lin and Ahrens (2000, 2005; 2010), Jiang (2002, 2004), and Zeelenberg and Pecher (2003), whereas the great majority of the words were selected by the authors of this study. The chosen words were concrete nouns, with half representing living entities and the other half non-living things. The living exemplars came from the following categories: people, professions, plants and animals; whereas, the non-living words were examples of things, objects, musical instruments, pieces of clothing, buildings and places. Previous studies (e.g., Zeelenberg & Pecher, 2003 or Li et al., 2009) have included the names of fruit, vegetables and body parts as living exemplars. However, these types of words were not selected as stimuli in this study as they might have been viewed as unclear. For example, words such as *peach* or *stomach* are not unanimously understood as living exemplars by either Chinese or English speakers. Furthermore, to reduce the use of the expectancy strategy by the participants, a list of 20 filler words was introduced, which were also concrete nouns denoting living or non-living entities. They were preceded by primes that represented the opposite category, i.e., a living prime preceded a non-living target and a non-living prime was followed by a living target, for example, *qīngwā* (青蛙) [frog] – pocket or *yǐzi* (椅子) [chair] - judge. The majority of the selected words were initially chosen in English and translated into Chinese. Once a complete list of stimuli had been prepared, it was verified by two bilingual, Mandarin, Chinese-English speakers.

All of the Chinese words were written in a simplified script; they were two-character lexical units, for example, *mǎyǐ* (蚂蚁) meaning ‘ant’ or *qìqiú* (气球) meaning ‘balloon’. Two-character words rather than the alternative one-character words were chosen due to the fact that the same stimuli were used in both the visual and auditory task. Since Chinese is characterised by a high degree of homophony, it might have been difficult for the participants to recognize single character words without context (Tan et al., 2000). The English words were from three to seven letters long (M = 5; SD = 1.1), whereas the Chinese characters varied in complexity from five to 25 strokes (M = 15; SD = 4.4). Owing to the difference in scripts, it was difficult to compare the two languages in terms of length; however, care was taken to ensure that all the Chinese words were bisyllabic and that all the English ones were either monosyllabic or bisyllabic. The printed word frequency for the Chinese words could not be established as the majority of the frequency counts available are provided for single character words, which do not reflect the frequency of bisyllabic characters. Therefore, an alternative source was employed to make sure that all the stimuli were commonly used nouns that were familiar to the participants, namely, a Chinese-English children’s dictionary (Amery & Cartwright, 2006). That is, words that did not exist as entries in the dictionary were removed from the list of stimuli. Two counterbalanced lists comprising 30 target words preceded by translation equivalents and 30 unrelated primes (words that had a different meaning) and 20 fillers were constructed. The participants viewed items from one list only so as to avoid a repetition effect.

The language questionnaire was designed online with the use of the Lime Survey platform and comprised three parts: personal details, a language ability scale, and a language preference section that aimed to establish the: type of bilingualism (late/early, simultaneous/successive), language history, English language ability and language preference.

5.3 Design and procedure

The masked priming task was run from L1 to L2 as well as in the opposite language direction. It was designed based on a similar procedure to that in Jiang (1999, Experiments 4 and 5), Jiang and Forster (2001, Experiment 1) and Schoonbaert et al. (2009, Experiments 1, 2, 3 and 4). The experiment started with a presentation of instructions on the computer screen. The same instructions were displayed in English for the L1 (Chinese primes) to L2 (English target) condition and in Chinese for the L2 to L1 condition. This choice was motivated by the fact that the participants were requested to attend only to the target words. The instructions stated that they were to press the YES key (L key on the computer keyboard), if the presented word was a living exemplar and the NO key (S key on the computer keyboard), if the target was not (appropriate YES and NO labels were put over the L and S keys on the computer keyboard). The instructions also included the information about a practice session and the number of practice trials. The practice session consisted of 12 examples (4 translation equivalents, 4 unrelated words and 4 fillers) and allowed the participants to familiarize themselves with the task requirements. This was followed by the main experiment, which comprised 80 trials in total (30 pairs of translation equivalents, 30 unrelated pairs of words, and 20 fillers).

Each experimental trial consisted of five sequential visual events, as presented in Figure 2 below. First, a forward mask was presented for 500ms in the form of ten hash marks (##########). Apart from acting as a mask for the prime, it also served as a fixation point.

Next, the prime was shown for 30ms[1], followed by a blank interstimulus interval of 50ms. Fourth, a row of ten italicised dollar marks (*$$$$$$$$$$*) was presented as a backward mask for 150ms. The purpose of introducing this was to disguise the prime and also to ensure that the participants would have enough time to process the L2 primes (Jiang, 1999). Finally, the target word appeared and remained on the screen until the participant responded or until 2500ms had elapsed. The SOA was equal to 230ms and the reaction times were measured from the target's onset until the response was given.

(Insert Figure 2 about here)

The primes and targets were displayed in the middle of a computer screen, with the English and Chinese primes being displayed in font size 36, and the targets in size 48. The English words were written in the Arial Black (Regular) font, whereas the Chinese ones were written in the SimSum font. The usual presentation of primes in lowercase and targets in uppercase was not possible in this study because of the difference in the scripts. The forward mask and backward mask were displayed in Arial Black font size 36. The type of the characters used as forward and backward masks differed in order to avoid the, so called, *pop-out effect* of the prime (Finkbeiner et al., 2004; Schoonbaert et al., 2009), a situation that occurs when a prime presented in between two identical masks appears to stand out from the background and thus is visible to the participants. The order of the trials was randomized for every participant. The stimulus presentation, reaction times (RTs), and error rates (ERs) were controlled by Superlab 4.5 software.

[1] The prime duration of 30ms was established during a piloting stage of this study. Two different prime durations were chosen initially, 30ms and 45ms. Participants who took part in the 45ms primes display reported seeing the primes consciously. They also reported that some of them (unrelated primes) interfered with their decisions about the target words. On the other hand, the informants who participated in the 30ms prime presentation either reported not seeing the primes at all or said they had seen them, but too briefly to be able to recognise them and for this reason prime duration was set at 30ms in the visual condition. Regarding this, Wang

The experiments took place in a quiet room and each participant was tested individually. First, after a short introduction given by the researcher, the instructions were presented in a written format on the computer screen, either in English or Chinese, depending on which condition of the task the participants were requested to attend to. Next, they practised giving answers in a trial session, which was then followed by the main experiment and the whole procedure lasted about seven minutes.

5.4 Results and discussion

Only correct responses were analysed. All outliers (i.e., RTs that were less than 200ms or 2.5*SD* below or above the participant's mean word reaction time) were removed (2%). Also, 5 items (*groom, fox, doll, clown, seal*) were discarded from the final analysis[2]. Latency data from the two tasks, (1) L2 to L1 visual priming, (2) L1 to L2 visual priming, were analysed in a single design with a MANOVA[2] in SPSS. Subjects (F_1) and items (F_2) were treated as random variables, RTs and ERs as dependent variables, and prime relatedness (translation equivalents or unrelated words) as well as language direction (L2 to L1 or L1 to L2) as independent variables. Prime relatedness was a within subject variable, and language direction was a between subjects variable in the subject analysis, whereas in the item analysis, these two variables were within item ones. Furthermore, additional analysis including English language proficiency as a covariate was performed (proficiency was measured on the basis of self-ratings aggregated across five language skills). This was motivated by Wang's (2013)

(2013) used a 50ms prime display, but used a low in frequency Chinese character (聶) as a forward mask for a better masking effect.

[2] It is likely that the word *groom* might have been understood as *broom*, the word *fox* might have been heard as *box*, and the word *clown* could have been understood by the participants as *cloud* or *crown*. Hence, instead of giving a correct answer ('yes' to a living entity) the participants responded erroneously by pressing a 'no' button. Also, it has to be admitted that the word *seal* is ambiguous, for it might refer to a living entity, an animal, and also to a non-living thing, namely, a stamp. Furthermore, the word *wáwa* (娃娃) which stands for a *doll* in English can be understood in Chinese as a *baby* (a living entity) or as a *doll* (a non-living thing). The ambiguity of the items might have led to a high percentage of participants' errors.

findings, which point to the relative bilingual balance in two languages as a more accurate explanation of the priming asymmetry rather than language proficiency alone.

We first report the analysis performed on the RTs. A significant main effect of the prime relatedness was found. This means that the targets that were preceded by translation equivalents, e.g., *lǎoshī* (老师) [teacher] - teacher were recognized faster (M = 832ms, SD = 224ms) than were those preceded by unrelated words, *chǒngwù* (宠物) [pet] - teacher (M = 892ms, SD = 252ms). This difference was statistically significant in both the subject and item analyses [F_1 (1, 48) = 15.85, $p < 0.001$; F_2 (1, 54) = 23.12, $p < 0.001$]. The reported difference of 60ms can be interpreted as a priming effect. Furthermore, the main effect of the language direction was significant in both the subject and item analyses [F_1 (1, 48) = 19.99, $p < 0.001$; F_2 (1, 54) =121.12, $p < 0.001$]. This effect indicates that the answers given to the target items presented in the L2 to L1 language direction, e.g., teacher - *lǎoshī* (老师) were faster (M = 748ms, SD = 121ms) than those recorded for words in the opposite language direction, *lǎoshī* (老师) - teacher (M = 996ms, SD = 270ms), with the average difference being 247ms. Finally, the analysis revealed that the interaction between prime relatedness and language direction was statistically significant in both the subject and item analyses [F_1 (1, 48) = 11.49, $p \leq 0.001$; F_2 (1, 54) = 19.55, $p < 0.001$]. This interaction was further explored using a series of paired-samples t-tests. The obtained findings indicate that there was a statistically significant difference between the translation equivalents (M = 936ms, SD = 274ms) and the unrelated items (M = 1056ms, SD = 267ms) in the L1 to L2 visual priming experiment [t (22) = -3.681, $p \leq 0.001$]. In contrast, the outcome of the analysis conducted on the RTs from the L2 to L1 visual priming was not statistically significant [t (26) = -0.831, $p > 0.05$]. That is, the translation equivalents (M = 743ms, SD = 118ms) were recognized approximately at the same time as the unrelated words (M = 753ms, SD = 125ms). The set of results reported above is consistent with the priming asymmetry effect, a strong priming effect in the L1 to L2 condition, but weak effect or lack of it in the opposite language direction.

(Insert Table 2 about here)

The MANOVA calculated on the errors revealed no statistically significant difference between the related (1,9%) and unrelated items (2,3%) [F_1 (1, 48) = 1.202, $p > 0.05$]. Furthermore, regarding the comparison between the two language directions, in the L2-L1 language direction the participants made 2,3% of errors compared to 2,6% in the L1-L2 language group, was not statistically significant [F_1 (1, 48) = 3.472, $p > 0.05$]. The interaction between prime relatedness and language group was also not significant [F_1 (1, 48) = 0.029, $p > 0.05$].

The additional analysis performed on the same set of data included English language proficiency as a covariate. It emerged that L2 fluency did not lead to any statistically significant differences in this comparison, [F_1 (1, 48) = 0.103, $p > 0.05$]. Also, the interaction between prime relatedness and proficiency was not statistically significant [F_1 (1, 48) = 0.728, $p > 0.05$].

6. Experiment two – auditory priming

The second experiment similarly to the first was aimed at addressing the priming effect and the priming asymmetry effect (as before we predicted a two-way interaction between the dependent factors), but it also sought to widen the scope of findings by investigating the conceptual level of representation through the window of the auditory modality. This type of experimental design has not been employed with bilingual speakers before and therefore, it was treated as exploratory in nature. Nevertheless, we predicted that a similar pattern of results to the visual domain (Experiment 1) would be observed, (i.e., a priming effect).

However, the effect would be reported only from L1 to L2 and no effect or a weak one would be observed in the opposite language direction. If information from a bilingual's known languages shares a common memory store, the modality through which this information is accessed should not influence the results obtained. However, a difference in RTs was expected, specifically, quicker responses in the visual modality compared to the auditory one, due to (1) the variation in task designs, and (2) the speed with which participants perceived, accessed, and processed information in the two domains.

6.1 Participants

Data in the auditory task were collected from 46 participants, who were recruited at the same two locations in Hong Kong. They were late learners of English, between the ages of 18 and 25, dominant in Mandarin Chinese and right-handed. 25 were requested to respond to English auditory targets (L1 to L2 condition) and 21 to provide answers to Chinese target words (L2 to L1) (between-subject design). The two groups of participants in the auditory task did not differ with regard to age [χ^2 (1) = 0.002, $p > 0.05$], gender [χ^2 (1) = 0.053, $p > 0.05$] and education [χ^2 (1) = 1.809, $p > 0.05$]. However, a difference was noted for (1) age at which the participants started learning English, $M_{ageL2\text{-}L1}$ = 8.80 (3.14) vs. $M_{ageL1\text{-}L2}$ = 10.48 (1.99), [t (44) = 4.385, $p \leq 0.000$] and (2) length of residency in Hong Kong, $M_{stayL2\text{-}L1}$ = 2.76 (1.71) vs. $M_{ageL1\text{-}L2}$ = 1.10 (.301), [t (44) = -2.109, $p < 0.05$]. Although the means were numerically similar, they significantly differed.

6.2 Materials

The stimuli were the same as in Experiment 1; however, they were presented to the participants in an auditory format via a set of headphones.

6.3 Design and procedure

Two versions of the auditory experiments were designed. In one of the sets, the primes were presented in Chinese and the targets in English (L1 to L2), in the other set the language direction was reversed (L2 to L1). Each set consisted of 12 practice trials and 80 experimental ones (60 critical targets and 20 fillers), each beginning with a presentation of white noise that lasted for one second. The white noise resembled a background conversation; however, it was not possible for the listener to determine the topic of the conversation, understand individual words or to determine the language spoken. After the initial 300ms of the 1 sec of the white noise display (forward mask), a time-compressed prime embedded in the white noise was played for a mean duration of 340ms (Chinese primes) or 370ms (English primes). Once the prime presentation ended, the white noise (backward mask) continued for another 360ms or 330ms. Next, the target was played for a mean duration of 680ms (English targets) or 740ms (Chinese targets) without any white noise in the background. At the end of each trial an interstimulus interval of one second was introduced to mark the ending of a single presentation trial (Figure 3).

(Insert Figure 3 about here)

The procedure of the auditory priming task resembled those used by Kouider and Dupoux (2005) and Dupoux et al. (2008). In both of these studies as well as in the current one, the primes were time compressed to 50% of their original duration[3] and they were preceded as well as being followed by white noise (by forward and backward masks). However, the

[3] In Kouider and Dupoux (2005), the primes were time compressed to 35%, 40%, 50%, or 70% of their original duration. The prime duration was manipulated in order to estimate the prime audibility, a rate at which the participants were aware of the primes. The results show that at the 35% and 40% rates the participants were mostly unaware of the primes; however, for the 50% and 70% rates the participants reported hearing the primes. In this study, a 50% time compression rate was used; however, to ensure that the participants would not be aware of the primes, they were embedded in white noise.

procedure used in this research differed in two aspects. First, the mask was used in the form of a non-language specific background conversation white noise rather than one obtained by reversing the primes. This recording was used because it more closely resembles natural human speech compared to undistinguishable white noise. Secondly, the targets were presented on their own, without white noise. This decision was made to ensure that the target words were clearly audible and easily recognisable by the participants, whereas the primes could not be consciously processed.

The stimuli were presented to the participants through a set of headphones. The words were read out loud by a male native speaker of English or one of Mandarin Chinese, having been recorded and edited with the Cool Edit Pro software. Editing involved trimming each sound before and after the word was spoken in such way that only the word itself was audible. Also, each prime word was time compressed to 50% of its original duration. The time compressed English primes were from 275ms to 400ms long with a mean of 340ms (*SD* = 32ms), whereas the Chinese were 325ms to 400ms long with a mean of 370ms (*SD* = 28ms). The targets were played at a normal speech rate. That is, the English targets were from 550ms to 800ms presented for a mean duration of 680ms (*SD* = 64ms), whereas the Chinese ones were from 650ms to 800ms long, with an average of 740ms (*SD* = 57ms) in length. The audio files with recorded words were presented to the participants by the Superlab 4.5 software and the recording of the RTs started at the onset of each word.

6.4 Results and discussion

Analysis was carried out in the same way as for the visual tasks. That is, after the initial trimming of the data, a MANOVA was performed to explore the main effects, followed by an investigation of the simple effects with the use of a paired-sample t-test.

A significant main effect of prime relatedness was found in both the subject and item analyses [F_1 (1, 44) = 26.94, $p < 0.001$; F_2 (1, 54) = 25.25, $p < 0.001$]. This effect demonstrates that target items that were preceded by translation equivalents (*M* = 1431ms, *SD* = 306ms) were recognized more rapidly by approximately 130ms than those that were preceded by unrelated words (*M* = 1562ms, *SD* = 402ms). Furthermore, the main effect of language direction was also statistically significant in both the subject and item analysis [F_1 (1, 44) = 35.81, $p < 0.001$; F_2 (1, 54) = 106.65, $p < 0.001$]. The difference of 449ms indicates that the items that were presented in the L2 to L1 condition (*M* = 1292ms, *SD* = 230ms) were responded to quicker than target words presented in the L1 to L2 language direction (*M* = 1741ms, *SD* = 311ms). Also, a statistically significant interaction between prime relatedness and language direction was recorded both in the subject and item analyses [F_1 (1, 44) = 26.48, $p < 0.001$; F_2 (1, 54) = 25.35, $p < 0.001$]. The follow-up t-test conducted to compare the latency data from the L1 to L2 auditory priming experiment demonstrated that translation equivalents (*M* = 1599ms, *SD* = 292ms) were responded to faster than were unrelated words (*M* = 1883ms, *SD* = 329ms) and that this difference was statistically significant [$t(20) = -6.091$, $p < 0.001$]. By contrast, the results from the L2 to L1 auditory priming were not statistically significant. The translation equivalents (*M* = 1291ms, *SD* = 244ms) were recognized at the same rate as the unrelated ones (*M* = 1292ms, *SD* = 216ms) [t (24) = -0.038, $p > 0.05$]. In general, these results demonstrate that there was a facilitative effect for the translation equivalents, but only in the L1 to L2 language direction. The overall pattern of the results noted for the auditory modality resembled that of visual one. In other words, the translation equivalents were recognized more quickly than were the unrelated words (priming effect); however, the difference was statistically significant only in the L1 to L2 language direction (priming asymmetry effect).

The comparison of errors conducted on the related (4.2%) and unrelated items (4.5%) was not statistically significant [F_1 (1, 44) = 0.108, $p > 0.05$]. However, the language group led to a difference in the reported results in that the participants made more mistakes when responding in the L1-L2 direction (13,7%) compared to the L2-L1 language group (5,3%), [F_1 (1, 44) = 18.701, $p \leq 0.001$]. The participants provided the most erroneous answers when responding in English, which can also be reflective of the fact that they were dominant Mandarin speakers. Finally, the interaction between prime relatedness and language group was near statistical significance [F_1 (1, 44) = 3.777, $p > 0.05$].

Furthermore, regarding the analysis performed on the auditory data, which included English language proficiency as a covariate pointed to null effects, no significant difference between prime relatedness and language proficiency was observed [F_1 (1, 44) = 1.293, $p > 0.05$]. The interaction between prime relatedness and proficiency was also not statistically significant [F_1 (1, 44) = 0.459, $p > 0.05$]. The same pattern of results has been demonstrated for the visual modality.

7. General discussion

The results obtained from the visual as well as auditory experiments have shown that the translation equivalents were recognized more rapidly than the unrelated targets in the L1 to L2 language direction. Thus, the observed priming effects suggest that the RHM's representation of the conceptual level also extends to Chinese-English bilingual speakers. The conceptual level is shared, at least for the concrete nouns of translation equivalents that represent both animate entities and inanimate things. Nonetheless, in the opposite language direction, (i.e., from L2 to L1), the participants responded to both types of targets at approximately the same rate. This pattern of results is consistent with a number of previous studies (e.g., Finkbeiner et al., 2004; Gollan et al., 1997; Jiang, 1999; Jiang & Forster, 2001;

Keatley et al., 1994) and it demonstrates the priming asymmetry effect. Moreover, the reported asymmetry is in line with the representation account captured by the RHM (Kroll & Steward, 1994). It seems that the strength of the connections between L1 and concepts is greater than that between L2 and concepts. That is, when the prime is presented in L1, more conceptual information is activated/available for processing and therefore, a stronger priming effect can be observed, whereas in the opposite language direction a weak effect or even inhibition (a negative effect) is observed in some cases (e.g., Finkbeiner et al., 2004; Jiang, 1999; Keatley et al., 1994). The asymmetry reported in this study is not unusual, for there have been a substantial number of investigations that have found a strong priming effect from L1 to L2, but a weak and inconsistent one in the opposite direction (e.g., Gollan et al., 1997; Jiang, 1999; Jiang & Forster, 2001; Keatley et al., 1994).

More recently, there have been several studies (e.g., Basnight-Brown & Altarriba, 2007; Duñabeitia et al., 2010; Duyck & Warlop, 2009b; Perea et al., 2008; Schoonbaert et al., 2009) that have shown a significant priming effect also in the L2 to L1 direction, but the effect was still smaller in magnitude than that from L1 to L2. Duñabeitia and colleagues (2010) made a comparison of several studies and attributed the asymmetry to the fact that the reviewed studies were conducted with unbalanced, non-simultaneous bilinguals. In the current study, the participants were dominant in Mandarin Chinese and most of them acquired English sequentially to Chinese. Hence, the priming effect was reported from the dominant language (L1) to the less dominant (L2) language, but it was not visible in the opposite direction. Furthermore, Duyck and Warlop (2009) reported that this priming effect from L2 to L1 has been found in experiments conducted with bilingual speakers living in an L2 dominant environment. The participants who took part in the current study were living in a fairly mixed linguistic environment, they used English at university, but Mandarin Chinese at home and with friends; however, they were still dominant in their L1. This might be yet another reason why the priming effect was not observed with this group of participants in the L2 to L1 language direction. Finally, as indicated by Wang (2013), language proficiency itself may not explain the priming asymmetry; the relative bilingual balance in two languages seems more accurate. In this study, language proficiency, which was recognised as a possible confound, did not play a role in the results obtained. The individual groups of participants were comparable in terms of their levels of English language knowledge; however, Chinese was their dominant language (i.e., reported by the participants as dominant in the language questionnaire and confirmed by the high percentage of errors in the L1-L2 language direction in the auditory modality). Language dominance can be seen here as a factor contributing to the priming asymmetry effect.

Additionally, the priming effect reported in the auditory modality in the L1 to L2 language direction appears to be greater in magnitude (284ms) than the effect in the visual modality (120ms). This suggests that while the priming effect and the asymmetry effect were present in both modalities, there are most likely differences in processing between the two. The results from this study resemble those obtained from monolingual investigations by Anderson and Holcomb (1995) and Holcomb and Neville (1990), that is, the priming effect was greater for the auditory modality than for the visual. This difference in response times might be attributed to the fact that “auditory stimuli cannot be recognized on the spot with the onset of stimulus presentation like visual stimuli but need to be at least partly articulated before the word can be identified” as explained by Degner (2011, p. 1718). In Anderson and Holcomb’s investigation, participants also gave slower answers to auditory stimuli than to visually presented words. The same pattern of findings was found by Holcomb and Neville, with Anderson and Holcomb (1995, p. 189) attributing these differences to two possible sources, “the availability of information over time or the attentional influences”. This explanation, however, can only hold partially, as the design of Anderson and Holcomb’s experiments is questionable. Regarding which, the researchers (1995) presented stimuli simultaneously at 0ms SOA, overlapping at 200ms SOA, or sequentially at 800ms SOA. It is likely that participants found it difficult to attend to a target word that is played at the same time as the prime, or when the beginning of the target is not clearly audible as the first 200ms overlaps with the last 200ms of the prime.

All in all, it has been shown in this study that an auditory task involving priming is a reliable investigative technique. It can be used well with bilingual participants in the form of a cross language priming task. Furthermore, the pattern of results obtained in the auditory task resembles that demonstrated in the visual one, (i.e., a priming effect, and a priming asymmetry effect). However, the applicability of the method needs to be explored further by applying a more constrained experimental design. First of all, the duration of the primes needs to be adjusted. As shown by Kouider and Dupoux (2005), the most robust subliminal priming effects can be observed when the primes are time compressed to 70% of the original duration (normal speech rate). Second, the type of mask has to be chosen carefully. It should resemble conversational or speech-like noise and most likely should be played continuously with the primes and targets being superimposed onto it. In this way, the experiment would appear more as a natural conversational situation (a gathering or a party-like situation), where from background noise one can decipher emerging snippets of conversation, (i.e., the target words during the experiment). This procedure should increase the ecological validity of the task. It is also important to verify whether tone, accent or the choice of female and male voices can influence the processing. It is likely that, for example, highly accented speech can push participants into a bilingual mode and lead to non-selective language processing, which would further have impact on the observed priming effect. Furthermore, other types of words (e.g., low frequency words or abstract words) should be investigated with this new paradigm to address sharedness at the conceptual level of representation in the bilingual mental lexicon.

To strengthen the validity of the task, the translation should be normed in both directions as, for instance, doll - 娃娃 /wáwa/ (doll or baby) might be much stronger than the translation applied in the opposite direction, (i.e., 娃娃 – doll). Nonetheless, the auditory priming task is seen as a useful technique that should be further developed and employed in investigations involving bilinguals. It can be employed with children, blind participants and less fluent L2 speakers (less proficient literates) to shed more light on the auditory language processing (Degner, 2011) and consequently, on the way in which conceptual information is stored in memory.

To sum up, the findings presented in this study can substantiate the theoretical predications of the RHM (Kroll & Stewart, 1994) in their original form. That is, evidence has been found for both a shared conceptual level of representation (priming effect in both the visual and auditory modalities) as well as for the differing strengths of interlexical connections (priming asymmetry effect in both modalities). To understand better the scope of findings obtained in this study, a decision was made to discuss them with reference to a computational model. Previous studies have often referred to BIA+ (van Heuven & Dijkstra, 2010), which is an extension of the BIA model (Dijkstra et al., 1998), for it contains not only orthographic representations and language nodes, but also phonological and semantic representations. The BIA+ model has been used before to simulate repetition and masked priming and the obtained results were in line with the empirical data (Dijkstra et al., 2010). Here, however, we have chosen to discuss our findings with reference to DevLex-II (Zhao & Li, 2010) (Figure 4), which is preferred over the BIA+, as it has been trained on the two languages of interest in this study, (i.e., Chinese and English).

(Insert Figure 4 about here)

DevLex-II has been used to simulate both the priming and priming asymmetry effects. Specifically, Zhao and Li (2013) implemented it to simulate both translation and semantic priming across Chinese and English under two conditions, (i.e., early vs. late L2 learning). In the experiment conducted by these two researchers, the network learned Chinese as L1 and English as L2, and different learning histories were also simulated, words in both languages were presented to the network at different intervals, with a significant lag for late L2 learning. It was demonstrated that the data generated by the model was consistent with several previous psycholinguistic studies (e.g., Basnight-Brown & Altarriba, 2007; Schoonbaert et al., 2009). That is, a stronger priming effect was observed from L1 to L2 than in the opposite language order, (i.e., L2 to L1). Also, the translation priming effect was stronger than that for semantic priming. Finally, the priming effect was stronger in magnitude for the late learners than for the early ones.

The priming asymmetry effect observed in this study is consistent with the one simulated by DevLex-II. Here, the asymmetry is explained in terms of the differing strength of connections between L1 and concepts and L2 and concepts, as represented by the RHM (Kroll & Stewart, 1994). Zhao and Li (2013), on the other hand, put forward an interesting alternative to the understanding of the priming asymmetry. According to these researchers, bilinguals might have a richer semantic representation or better understanding of words in L1 as compared to L2 and therefore, there is less confusion or lexical competition between lexical items in that language. However, since “L2 items are represented in more densely populated neighbourhoods and hence have increased lexical competition from their nearby lexical items” (Zhao & Li, 2013:301), this may lead to an insufficient level of activation (when presented as primes) that will then spread to target words. Furthermore, similarly to the findings presented in this study, Zhao and Li (2013) also observed that bilinguals respond quicker to target words presented in L1 than L2. Here, this difference was attributed to the participants' language dominance in Chinese. However, Zhao and Li (2013) offered an interesting account based on the representation of words in the bilingual lexicon rather than on the participants' level of proficiency. That is, these researchers explained that L2 words are more densely distributed (on semantic maps based on simulations) and therefore there is more lexical competition taking place between different L2 lexical items, which, in turn, leads to overall slower reaction times in L2 in an LDT. DevLex II offers insightful explanations with regard to the priming and the priming asymmetry effects that have not been considered by other psycholinguistic models and this, yet again, endorses the importance of interdisciplinary work.

To conclude this section, both the Revised Hierarchical Model (Kroll & Stewart, 1994) as well as DevLex II (Li, Zhao, McWhinney, 2007) have their strengths, for they allow for the posing of new questions and the formulating of new hypotheses; however, they also face certain limitations. Hence, they should be seen as transitional ones (Pavlenko, 2009). Kroll and Tokowicz (2005, p.531) have advocated that memory models need to be able to account for "distinctions between levels of language representations, differences in components of processing associated with unique task goals in comprehension versus production, and the consequences of the developmental aspect of language experience". This statement should be treated as guidance for developing new models that will act as hypothesis generators and as roadmaps (Brysbaert & Duyck, 2010) that will aid further our understanding of the bilingual lexical memory's organization and processing.

8. Conclusions

The Revised Hierarchical Model (Kroll & Stewart, 1994) was tested with reference to Chinese-English bilinguals in both the visual and auditory modalities. Despite language distance, it was demonstrated that Chinese-English bilinguals have a shared conceptual level of representation (priming effect) and that they activate more conceptual information when accessing the meanings of words in L1 (priming asymmetry effect) in both modalities. It has also been shown that cross-language priming in an auditory modality can be observed and that this type of task should be further exploited by carrying out future investigations with a more constrained experimental design. Nevertheless, this study was conducted with a group of L1-dominant Chinese-English bilinguals and employed only concrete nouns as stimuli. To extend the findings of this research, future work should look more into processing and representation of words that have multiple meanings/multiple translations, abstract nouns or verbs with multilingual groups of participants. Pursuing such research avenues will help validate findings that so far have been limited to bilingual, mostly Indo-European groups of participants, and at the same time will provide a more comprehensive picture of an otherwise rather skewed picture (Pavlenko, 2009) of the bilingual mental lexicon.

References

Altarriba, J., & Basnight-Brown, D. M. (2009). An Overview of Semantic Processing in Bilinguals: Methods and Findings. In A. Pavlenko (Ed.), *The bilingual mental lexicon. Interdisciplinary approaches* (pp. 79–98): Multilingual Matters.

Amery, H., & Cartwright, S. (2006). *First Thousand Words in Chinese*: Usborne Publishing Ltd.

Anderson, J. E., & Holcomb, P. J. (1995). Auditory and visual semantic priming using different stimulus onset asynchronies: An event related brain potential study. *Psychophysiology, 32*(2), 177-190.

Azuma, T., & Van Orden, G. C. (1997). Why SAFE Is Better Than FAST: The Relatedness of a Word's Meanings Affects Lexical Decision Times. *Journal of Memory and Language, 36*(4), 484-504.

Basnight-Brown, D. M., & Altarriba, J. (2007). Differences in semantic and translation priming across languages: The role of language direction and language dominance. *Memory & cognition, 35*(5), 953-965.

Brysbaert, M., & Duyck, W. (2010). Is it time to leave behind the Revised Hierarchical Model of bilingual language processing after fifteen years of service? *Bilingualism: Language and Cognition, 13*(03), 359-371.

Chen, H. C., & Ng, M. L. (1989). Semantic facilitation and translation priming effects in Chinese-English bilinguals. *Memory & cognition, 17*(4), 454-462.

De Groot, A. M. B. (1995). Determinants of bilingual lexicosemantic organisation. *Computer Assisted Language Learning, 8*(2-3), 151-180.

Degner, J. (2011). Affective priming with auditory speech stimuli. *Language and Cognitive Processes, 26*(10), 1710-1735.

Dijkstra, T., Van Heuven, W. J., & Grainger, J. (1998). Simulating cross-language competition with the bilingual interactive activation model. *Psychologica Belgica*.

Dijkstra, T., & Van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition, 5*(03), 175-197.

Dijkstra , T., Hilberink-Schulpen, B., & Van Heuven, W. J. B. (2010). Repetition and masked form priming within and between languages using word and nonword neighbors. *Bilingualism: Language and Cognition,*13 (03), 341-357.

Dong, Y., Gui, S., & MacWhinney, B. (2005). Shared and separate meanings in the bilingual mental lexicon. *Bilingualism: Language and Cognition, 8*(03), 221-238.

Dufour, R., & Kroll, J. F. (1995). Matching words to concepts in two languages: A test of the concept mediation model of bilingual representation. *Memory & Cognition, 23*(2), 166-180.

Duñabeitia, J. A., Perea, M., & Carreiras, M. (2010). Masked translation priming effects with highly proficient simultaneous bilinguals. *Experimental Psychology, 57*(2), 98-107.

Dupoux, E., Gardelle, V., & Kouider, S. (2008). Subliminal speech perception and auditory streaming. *Cognition, 109*(2), 267-273.

Durgunolu, A. Y., & Roediger, H. L. (1987). Test differences in accessing bilingual memory. *Journal of Memory and Language, 26*(4), 377-391.

Duyck, W., & Warlop, N. (2009a). Translation priming between the native language and a second language: New evidence from Dutch-French bilinguals. *Experimental psychology, 56*(3), 173-179.

Duyck, W., & Warlop, N. (2009b). Translation priming between the native language and a second language: New evidence from Dutch-French bilinguals. *Experimental Psychology, 56*(3), 173.

Finkbeiner, M., Forster, K., Nicol, J., & Nakamura, K. (2004). The role of polysemy in masked semantic and translation priming. *Journal of memory and language, 51*(1), 1-22.

Francis, W. S. (2005). Bilingual semantic and conceptual representation. In J. F. Kroll & A. De Groot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 251–267): Oxford University Press, USA.

Francis, W. S., Fernandez, N. P., & Bjork, R. A. (2010). Conceptual and non-conceptual repetition priming in category exemplar generation: Evidence from bilinguals. *Memory, 18*(7), 787-798.

French, R. M., & Jacquet, M. (2004). Understanding bilingual memory: models and data. *Trends in Cognitive Sciences, 8*(2), 87-93.

Gollan, T. H., Forster, K. I., & Frost, R. (1997). Translation priming with different scripts: Masked priming with cognates and noncognates in Hebrew-English bilinguals. *Learning, Memory, 23*(5), 1122-1139.

Grainger, J. (2008). Cracking the orthographic code: An introduction. *Language and Cognitive Processes, 23*(1), 1-35.

Grainger, J., & Beauvillain, C. (1988). Associative priming in bilinguals: Some limits of interlingual facilitation effects. *Canadian Journal of Psychology/Revue canadienne de psychologie, 42*(3), 261-273.

Grosjean, F. (1998). Studying bilinguals: Methodological and conceptual issues. *Bilingualism: Language and Cognition, 1*(02), 131-149.

Guasch, M., Sánchez-Casas, R., Ferré, P., & García-Albea, J. E. (2011). Effects of the degree of meaning similarity on cross-language semantic priming in highly proficient bilinguals. *Journal of Cognitive Psychology, 23*(8), 942-961.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language and Cognitive Processes, 5*(4), 281-312.

Jiang, N. (1999). Testing processing explanations for the asymmetry in masked cross-language priming. *Bilingualism: Language and Cognition, 2*(01), 59-75.

Jiang, N. (2002). Form–meaning mapping in vocabulary acquisition in a second language. *Studies in Second Language Acquisition, 24*(04), 617-637.

Jiang, N. (2004). Semantic transfer and its implications for vocabulary teaching in a second language. *The modern language journal, 88*(3), 416-432.

Jiang, N., & Forster, K. I. (2001). Cross-Language Priming Asymmetries in Lexical Decision and Episodic Recognition. *Journal of memory and language, 44*(1), 32-51.

Jin, Y. S. (1990). Effects of concreteness on cross-language priming in lexical decisions. *Perceptual and Motor Skills, 70*(3), 1139-1154.

Keatley, C. W., Spinks, J. A., & De Gelder, B. (1994). Asymmetrical cross-language priming effects. *Memory & cognition, 22*(1), 70-84.

Kim, J., & Davis, C. (2003). Task effects in masked cross-script translation and phonological priming. *Journal of memory and language, 49*(4), 484-499.

Kouider, S., & Dupoux, E. (2005). Subliminal speech priming. *Psychological Science, 16*(8), 617.

Kroll, J. F., Michael, E., Tokowicz, N., & Dufour, R. (2002). The development of lexical fluency in a second language. *Second language research, 18*(2), 137-171.

Kroll, J. F., & Stewart, E. (1994). Category interference in translation and picture naming: Evidence for asymmetric connections between bilingual memory representations. *Journal of Memory and Language, 33*, 149-149.

Kroll, J. F., & Tokowicz, N. (2005). Models of Bilingual Representation and Processing: Looking Back and to the Future. In J. F. Kroll & A. De Groot (Eds.), *Handbook of Bilingualsim*: Oxford University Press.

Kroll, J. F., van Hell, J. G., Tokowicz, N., & Green, D. W. (2010). The Revised Hierarchical Model: A critical review and assessment. *Bilingualism: Language and Cognition, 13*(3), 373 - 381

Li, L., Mo, L., Wang, R., Luo, X., & Chen, Z. (2009). Evidence for long-term cross-language repetition priming in low fluency Chinese–English bilinguals. *Bilingualism: Language and Cognition, 12*(01), 13-21.

Lim, V. P., Liow, S. J. R., Lincoln, M., Chan, Y. H., & Onslow, M. (2008). Determining language dominance in English-Mandarin bilinguals: Development of a self-report classification tool for clinical use. *Applied Psycholinguistics, 29*(3), 389.

Lin, C. C., & Ahrens, K. (2000). Calculating the number of senses: Implications for ambiguity advantage effect during lexical access. *Proceedings of the ISCLL VII 2000*, 141-154.

Lin, C. C., & Ahrens, K. (2005). How many meanings does a word have? Meaning estimation in Chinese and English *Language acquisition, change and emergence: Essays in evolutionary linguistics* (pp. 437–464).

Lin, C. J. C., & Ahrens, K. (2010). Ambiguity advantage revisited: Two meanings are better than one when accessing Chinese nouns. *Journal of psycholinguistic research, 39*(1), 1-19.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (Vol. 11, pp. 264-336).

Neely, J. H., Keefe, D. E., & Ross, K. L. (1989). Semantic priming in the lexical decision task: Roles of prospective prime-generated expectancies and retrospective semantic matching. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*(6), 1003-1019.

Pavlenko, A. (1999). New approaches to concepts in bilingual memory. *Bilingualism: Language and Cognition, 2*(03), 209-230.

Pavlenko, A. (2009). *The bilingual mental lexicon: interdisciplinary approaches* (Vol. 70). Bristol: Multilingual Matters.

Perea, M., Duñabeitia, J. A., & Carreiras, M. (2008). Masked associative/semantic priming effects across languages with highly proficient bilinguals. *Journal of memory and language, 58*(4), 916-930.

Potter, M. C., So, K. F., Eckardt, B. V., & Feldman, L. B. (1984). Lexical and conceptual representation in beginning and proficient bilinguals. *Journal of Verbal Learning and Verbal Behavior, 23*(1), 23-38.

Schoonbaert, S., Duyck, W., Brysbaert, M., & Hartsuiker, R. J. (2009). Semantic and translation priming from a first language to a second and back: Making sense of the findings. *Memory & cognition, 37*(5), 569-586.

Sunderman, G., & Kroll, J. F. (2006). First language activation during second language lexical processing: An investigation of lexical form, meaning, and grammatical class. *Studies in Second Language Acquisition, 28*(03), 387-422.

Talamas, A., Kroll, J. F., & Dufour, R. (1999). From form to meaning: Stages in the acquisition of second-language vocabulary. *Bilingualism: Language and Cognition, 2*(01), 45-58.

Tan, L. H., Spinks, J. A., Gao, J. H., Liu, H. L., Perfetti, C. A., Xiong, J., et al. (2000). Brain activation in the processing of Chinese characters and words: a functional MRI study. *Human Brain Mapping, 10*(1), 16-27.

van Heuven, W. J. B., & Dijkstra, T. (2010). Language comprehension in the bilingual brain: fMRI and ERP support for psycholinguistic models. *Brain research reviews, 64*(1), 104-122.

van Heuven, W. J. B., Dijkstra, T., & Grainger, J. (1998). Orthographic neighborhood effects in bilingual word recognition. *Journal of Memory and Language, 39*, 458-483.

Voga, M., & Grainger, J. (2007). Cognate status and cross-script translation priming. *Memory & cognition, 35*(5), 938-952.

Wang, X. (2013). Language dominance in translation priming: Evidence from balanced and unbalanced Chinese–English bilinguals. *The Quarterly Journal of Experimental Psychology, 66*(4), 727-743.

Wang, X., & Forster, K. I. (2010). Masked translation priming with semantic categorization: Testing the Sense Model. *Bilingualism: Language and Cognition, 13*(3), 1-14.

Zeelenberg, R., & Pecher, D. (2003). Evidence for long-term cross-language repetition priming in conceptual implicit memory tasks. *Journal of memory and language, 49*(1), 80-94.

Zhao, X., & Li, P. (2010). Bilingual lexical interactions in an unsupervised neural network model. *International Journal of Bilingual Education and Bilingualism, 13*(5), 505-524.

Zhao, X., & Li, P. (2013). Simulating cross-language priming with a dynamic computational model of the lexicon. *Bilingualism: Language and Cognition, 16*(2), 288-303.

	listen	speak	write	read	grammar
			visual modality		
L2-L1	3.03 (0.43)	2.77(0.50)	2.81 (0.48)	3.22 (0.50)	3.11 (0.69)
L1-L2	3.04 (0.56)	2.73 (0.54)	2.78 (0.67)	3.17 (0.57)	3.08 (0.66)
			auditory modality		
L2-L1	2.76 (0.52)	2.60 (0.57)	2.68 (0.55)	3.12 (0.52)	2.80 (0.57)
L1-L2	2.80 (0.67)	2.47 (0.67)	2.61 (0.74)	2.95 (0.58)	2.90 (0.76)

Table 1. *Means based on participants self-rating of the main English language skills on a four point Likert scale (1 - not well at all; 2 - not so well; 3 - pretty well; 4 - very well). Standard deviations are included in the parenthesis. The mode for all skills was 3/pretty well; whereas, the range was equal 2 (2 – 4) for listening, reading (receptive skills), and grammar; and 3 (1 – 4) for speaking and writing (productive skills). No statistically significant differences were found between the individual groups.*

	visual		auditory	
	L2 - L1	**L1 - L2**	**L2 - L1**	**L1 - L2**
translation equivalents	743 (118)	936 (274)	1291 (224)	1599 (292)
unrelated	753 (125)	1056 (267)	1292 (216)	1883 (329)
priming effect	10	120***	1	285***

Table 2. *Mean reaction times and priming effects in the visual and auditory modalities: ***p < 0.001*

[1] Age in this study was measured as a categorical variable.
[2] The analysis conducted for this study followed other major publications, in which subject and item analysis on RTs and ERs has been performed (Duñabeitia et al., 2010; Jiang, 1999; Jiang & Forster, 2001; Schoonbaert et al., 2009)